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Temporal perception in joint action: This is MY action

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Abstract

Here we investigated the temporal perception of self- and other-generated actions during sequential joint actions. Participants judged the perceived time of two events, the first triggered by the participant and the second by another agent, during a cooperative or competitive interaction, or by an unspecified mechanical cause. Results showed that participants perceived self-generated events as shifted earlier in time (*anticipation* temporal judgment bias) and non-self-generated events as shifted later in time (*repulsion* temporal judgment bias). This latter effect was observed independently from the kind of cause (i.e., agentive or mechanical) or interaction (i.e., cooperative or competitive). We suggest that this might represent a mental process which allows discriminating events that cannot plausibly be linked to one's own action. When an event immediately follows a self-generated one, temporal judgment biases operate as self-serving biases in order to separate self-generated events from events of another physical causality.

Keywords: Temporal binding; Agency; Causality; Cooperation; Competition; Intentional binding; Motor awareness

1. Introduction

As Hume famously argued (1739/1888), causality cannot be perceived directly, but must be inferred from the temporal contiguity and contingency of the events. According to this view, time provides the perceptual input from which causal representations are derived: we expect the cause to be contiguous with the effect and we tend, therefore, to perceive an event precedent and contiguous with another to be the cause of that event. On this account, perception of time shapes our experience of causality. Intriguingly, however, the reverse relationship also exists: perception of causality can shape our experience of time. It has been showed, for instance, that strong causal beliefs affect temporal order perception such that if the event A is believed to have caused the event B, then A is perceived as having occurred before B, even when this leads to a reversal of the objective temporal order (Bechlivanidis and Lagnado, 2013 and Bechlivanidis and Lagnado, 2016). Moreover, when the events A and B are considered to be causally related, they also appear closer together in time, that is they become temporally bounded.

This effect of Temporal Binding (TB, hereinafter) has been described as the subjective compression of the time interval between actions and their effects (Frith, 2013 and Haggard and Tsakiris, 2009). When people perform an action A (e.g., a key press), the perceived time of the action is shifted later in time and the perceived time of the event B (e.g., a tone) is shifted earlier in time, resulting in temporal binding of the two events.

It has been argued that TB is an essential feature of the comprehension of cause–effect relations (Buehner, 2012, Buehner and Humphreys, 2009 and Cravo et al., 2011), and a distinctive marker of voluntary actions which connotes the experience of agency (Frith, 2014 and Haggard et al., 2002). In this vein, TB has been used as indirect measure of pre-reflective sense of agency (for a review see Moore & Obhi, 2012). Interestingly, however, TB occurs not only for self-generated actions, but also for actions performed by others. Wohlschläger, Haggard, Gesierich, and Prinz (2003), for example, compared the perceived onset time of self-generated actions, other-generated actions, and machine-generated actions. TB was observed both for self- and other-generated actions, but not for machine-generated actions, suggesting that TB might function as an *agent-serving bias*, binding an effect to the agent who caused it (Frith, 2013), whether self or other.

Similar effects have been documented in joint actions, when two or more individuals coordinate their actions in space and time to achieve a common goal. Strother, House, and Obhi (2010), for example, used a joint action task in which two participants jointly performed a task (a key press) that had a single effect-event (a tone). Participants showed a similar TB for both self-generated and other-generated actions. These findings have been taken to suggest that, during joint action, individuals build up a shared motor plan, which incorporates others' actions into their own motor system (Haering and Kiesel, 2012, Obhi and Hall, 2011 and Wohlschläger et al., 2003). The study by Strother et al. (2010) was explicitly designed to be highly ambiguous about which of the two agents had caused an event. In everyday circumstances, however, a joint goal can often only be accomplished through a *sequence* of actions. Therefore, it remains unclear whether these findings generalize to social situations in which, rather than co-acting the same action, agents coordinate their actions sequentially in time.

To investigate this issue, here we employed a modified version of the time judgment paradigm used by Libet, Gleason, Wright, and Pearl (1983), in which participants initiated an action and experienced an effect (tone) immediately prior to a second person joining in and making a similar action to produce a second tone. Participants were asked to judge the timing of either the first (self-generated) tone or the second (other-generated) tone in two different settings: a cooperative setting and a competitive setting. Cooperation and competition have been shown to influence to degree to which another person's action is incorporated into one's own motor plan. For example, de Bruijn, Miedl, and Bekkering (2008) found that fast responders in a competitive game are able to block out response plans of competitors. On the contrary, cooperation has been shown to facilitate the creation of a shared motor plan (Liepelt et al., 2011 and Sebanz et al., 2006). We reasoned that if TB in joint action reflects co-representation, then it might similarly vary as a function of setting. Specifically, one would expect TB for the effects of the second person's action when the second person acts cooperatively, but not when he/she acts competitively. In this latter case, TB might vanish or even reverse into a 'repulsion' effect, with action and effect perceived further apart in time than they actually are (Haggard, Poonian, & Walsh, 2009).

2. Experiment 1

2.1. Participants

Twenty right-handed volunteers (15 females, 5 males; age range = 19–30 years) participated in the experiment. All had normal or corrected-to-normal vision and hearing and were naïve with respect to the purpose of the study. The experimental procedures were approved by the local Ethics Committee and were carried out in accordance with the principles of the revised Helsinki Declaration (World Medical Associations General Assembly, 2008).

2.2. Apparatus

Participants were administered a modified version of the time judgment paradigm used by Libet et al. (1983). Stimuli were presented on a 15 inches pc monitor (800 × 600 pixels; refresh rate 85 Hz) at a viewing distance of 70 cm. Participants were seated in a comfortable chair alongside a co-actor. At the beginning of each trial, an image of a clock marked at conventional '5-min' intervals (Libet et al., 1983) and a single hand, equal to the radius of the clock (approximately 10 cm long), appeared. The initial position of the hand was determined randomly. The hand remained stationary for 1000 ms, at which point began to rotate clockwise with a period of 2220 ms. The hand rotated continuously until the end of each trial.

E-Prime V1.0 was used to control stimuli presentation and data collection (Psychology Software Tools, Inc).

2.3. Procedure

Three persons took part to each experimental session. Unbeknown to participants, two of them were co-experimenters.

Each participant performed the time judgement task in three experimental conditions: 'Cooperation', 'Competition', and 'Sequence', run in separate blocks (40 trials each).

The participant and a co-experimenter worked in pair in front of the monitor and operated one response key each with their right index finger (Fig. 1a).

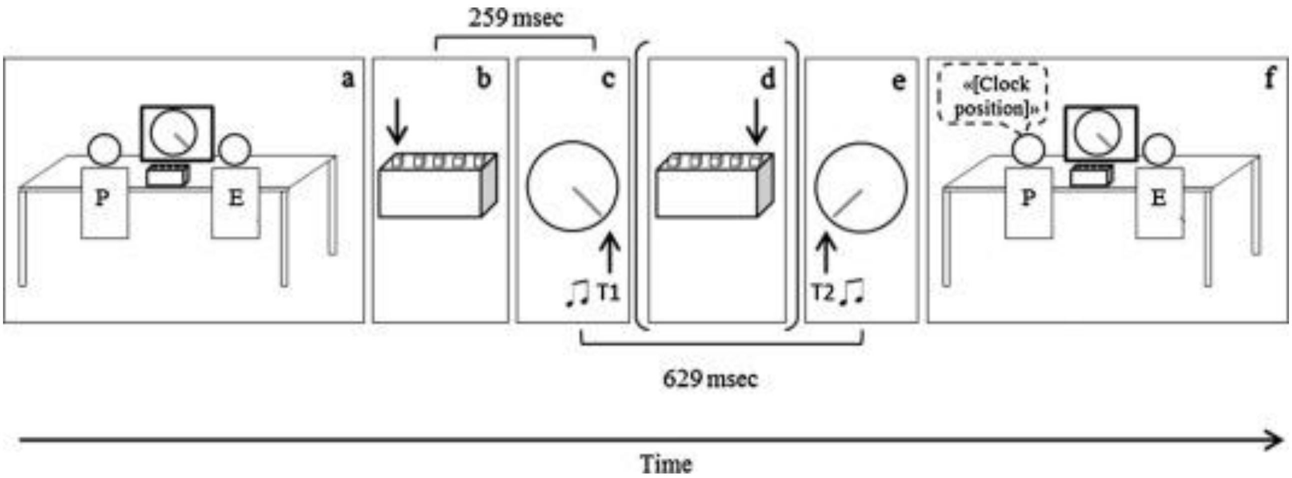

Fig. 1. Schematic reproduction of the experimental procedure. (a) The participant (P) was invited to watch the clock, on which the hand was rotating; (b) at a time of his/her choice, the participant performed a key press; (c) after an interval of 259 ms, the key press was followed by T1 (1000 Hz), and the participant had to note the clock position at time of T1; (d) the co-experimenter (E) (fictitiously) performed a key press (only for 'Cooperation' and 'Competition' conditions); (e) after an interval of 629 ms from T1, T2 (500 Hz) occurred, and the participant had to note the clock position at time of T2; (f) the participant had to report the clock position at time of T1 or T2, according to instructions.

In the 'Cooperation' condition, the participant was instructed to perform a key press at a time of his/her choice (Fig. 1b) with the only restriction to wait an entire hand clock rotation. He/she was encouraged to avoid initiating key presses at pre-determined or stereotyped times or specific positions of the minute-hand (e.g. when the hand was on the '30'). The participant's key press triggered an effect tone (a 100 ms tone, 1000 Hz) (T1), which appeared after a 259 ms interval (Fig. 1c). This tone served as a go-stimulus for the co-experimenter to perform, as fast as possible, the second key press (Fig. 1d), followed by a second tone (a 100 ms tone, 500 Hz) (T2). This second tone occurred after a fixed interval of 629 ms relative to T1 (Fig. 1e). The duration of the T1–T2 interval was determined so to produce the impression of a causal relation between the co-experimenter's key press and the appearance of T2 (see Determination of the T1–T2 interval, below). Hand rotation continued for a random period between 555 and 925 ms after T2 and then stopped.

The participant was asked to judge either T1 or T2 (Fig. 1f). Instructions of which of the two tones was to be judged appeared every ten trials in counter-balanced order (Fig. 2b). He/she was encouraged to be as precise as possible in making the verbal reports, also using the intervals not marked on the clock face.

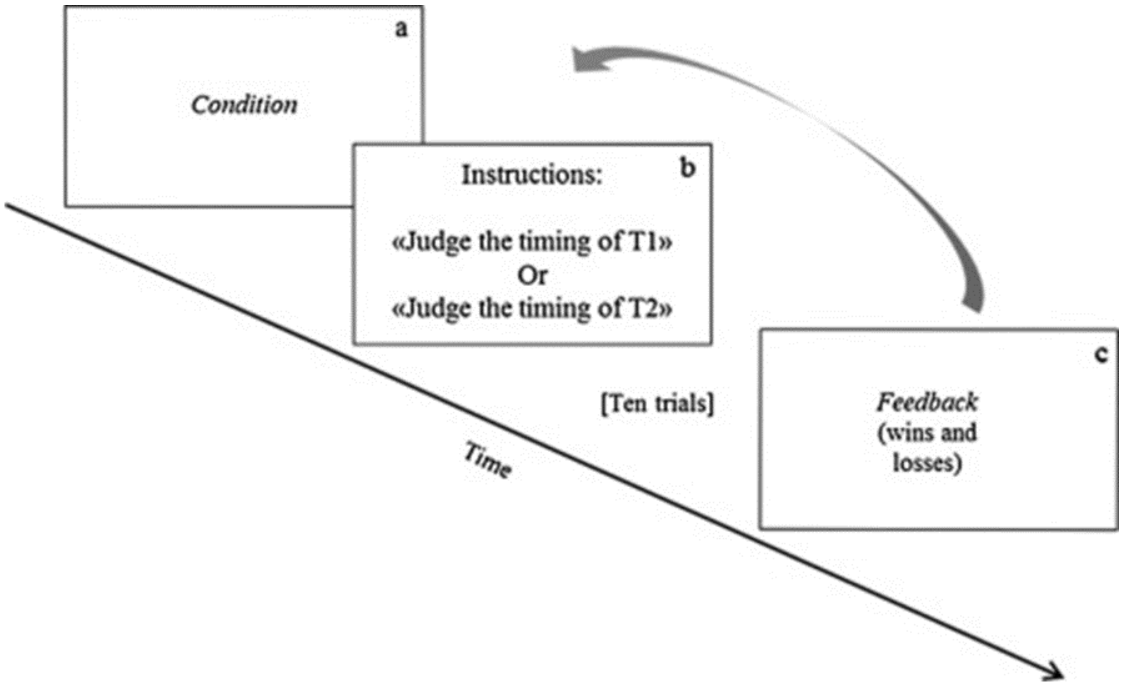

Fig. 2. Schematic reproduction of instructions and feedbacks for 'Cooperation', 'Competition', 'Sequence' conditions; (a) the indication of the ongoing condition was displayed at the beginning of each block; (b) instructions indicated the tone to be judged for the next ten trials (T1 or T2); (c) after ten trials a feedback was given (wins and losses) (only for 'Cooperation' and 'Competition' conditions). This was repeated until forty trials were performed.

Importantly, in this condition, the participant and the co-experimenter were instructed to coordinate their actions, as if they wanted to create "a melody" with the two tones. In order to stress the velocity (thus keeping credible the fixed interval between T1 and T2 across conditions), they were instructed to coordinate their actions as fast as possible. To strengthen this, they were told that the software controlling the experiment was automatically comparing their performances with those of previous participants, and that they had to be faster than previous participants in coordinating their actions. Every ten trials a fictitious feedback was given, that could be either ‘You are winning’ or ‘You are not winning’ (meaning that they succeeded or not in being faster than previous participants). A total of four (fictitious) feedbacks was given, indicating twice wins and twice losses (random order) (Fig. 2c).

The procedure of the ‘Competition’ condition was the same as the ‘Cooperation’ condition. Importantly, ‘Cooperation’ and ‘Competition’ conditions differed on the base of the following instructions. In the ‘Competition’ condition, the participant and the co-experimenter were told that the co-experimenter had to perform the key press as fast as possible, as if he wanted to “wipe out” T1. Again, they were told that the software controlling the experiment was automatically comparing their performances with those of previous participants. The co-experimenter was “the winner” if he was able to have a better performance of previous participants, otherwise the participant was “the winner”. Again, every ten trials a fictitious feedback was given, and it could be either ‘Participant 1 is winning’ (referring to the participant) or ‘Participant 2 is winning’ (referring to the co-experimenter). A total of four (fictitious) feedbacks was given, indicating twice ‘Participant 1 is winning’ and twice ‘Participant 2 is winning’ (random order) (Fig. 2c).

The co-experimenters were assigned to the conditions in a pseudo-randomized order, so that the same co-experimenter was never associated to the ‘Cooperation’ and the ‘Competition’ conditions in the same experimental session.

In the ‘Sequence’ condition, the participant was instructed to perform a key press at a time of his/her choice, with the same restrictions and indications of other conditions (Fig. 1b). After a delay of 259 ms, T1 occurred (100 ms, 1000 Hz) (Fig. 1c). This was followed by T2 (100 ms, 500 Hz) after a fixed interval (629 ms) (Fig. 1e). Similarly to what required in the ‘Cooperation’ and the ‘Competition’ conditions, the participant had to judge the perceived timing of T1 or T2, and again instructions of which of the two tones was to be judged appeared every ten trials in counter-balanced order (Fig. 2b). During this condition, the co-experimenter seated next to the participant, acting as a passive observer.

The order of ‘Cooperation’, ‘Competition’, ‘Sequence’ conditions was randomized across participants. In all conditions, both the participant and the co-experimenter wore earphones; in addition, the participant wore isolating headphones.

2.4. Assessment of TB for self-generated and other-generated actions

Before the main experiment, participants were pre-tested to assess TB for self-generated and other-generated actions in isolation (‘Action’ and ‘Observation’ conditions, respectively; 40 trials each).

In the ‘Action’ condition, the participant was verbally instructed to perform a key press at a time of his/her choice, with the same restrictions and indications of other conditions. The key press was followed by a short auditory stimulus (100 ms tone, 1000 Hz) after a delay of 259 ms. As for the main experiment, the participant was asked to report verbally the position of the hand at the time of the self-generated tone and encouraged to be as precise as possible in making the verbal reports, also using the intervals not marked on the clock face. During this condition, the co-experimenter seated next to the participant, acting as a passive observer.

In the 'Observation' condition, the same instructions and constraints were given to a co-experimenter. The co-experimenters were assigned to this condition randomly across participants. The key press was followed by a short auditory stimulus (100 ms tone, 500 Hz) after a delay of 259 ms. The participant was asked to report verbally the position of the hand at the time of the tone generated by the co-experimenter.

Participants started from the 'Action' condition or the 'Observation' condition in counter-balanced order.

2.5. Determination of the T1–T2 interval

The fixed interval between T1 and T2 used in the experimental conditions ('Cooperation', 'Competition', 'Sequence') was established some days before the experiment by training the co-experimenters. Specifically, the co-experimenters were trained to perform a key press immediately after T1, in the sequence described above, while the main experimenter acted as "participant". The mean reaction times of the co-experimenters during the training were used to set the interval between T1 and T2. After the training, four pilot sessions were conducted with random participants. These pilots were identical to the experiment. After each pilot session, participants were asked if they perceived T2 as caused by the co-experimenter's key press. The time interval between T1 and T2 was adjusted on the base of their reports, and then fixed when they reported no doubts on the causal relation between the co-experimenter's key press and T2.

2.6. Debriefing

After each experimental session (including the main experiment and the assessment of TB for self-generated and other-generated actions), participants were debriefed in order to check the efficacy of the experimental manipulations. All participants reported a clear experience of causality between the co-experimenter's key press and T2, and no suspicion about the fixed interval. Participants were also explained that there was no real automatic comparison with previous participants and that, therefore, the feedback on their performances was fictitious. Again, they did not report doubts or scepticism about the automatic comparison or about the fictitious feedbacks.

2.7. Data analysis

The position of the clock hand at the time of the tone was recorded on a computer for off-line analysis. The temporal resolution of response times was 37 ms. We calculated a*judgment error* (ms) for each trial by subtracting the position of the clock at the tone presentation from the participant's judgments of when the tone occurred. Hence, negative values indicate anticipated perception, whereas positive values indicate delayed perception. A few trials (1.63%) were excluded from the analysis because of errors by the participant or the experimenter during the coding. Mean judgment errors were used for statistical analysis.

2.8. Results for the self-generated actions (Action) and the other-generated actions (Observation)

A paired sample *t*-test on mean judgment errors revealed no significant difference ($t_{(19)} = -1.369$, $p = .187$) between the Action ($M = -16.07$, $SE = 4.13$) and the Observation ($M = -7.47$, $SE = 5.85$) conditions (Fig. 3). In line with previous reports, this suggests that an *anticipation* temporal judgment bias applied to both self- and other-generated events.

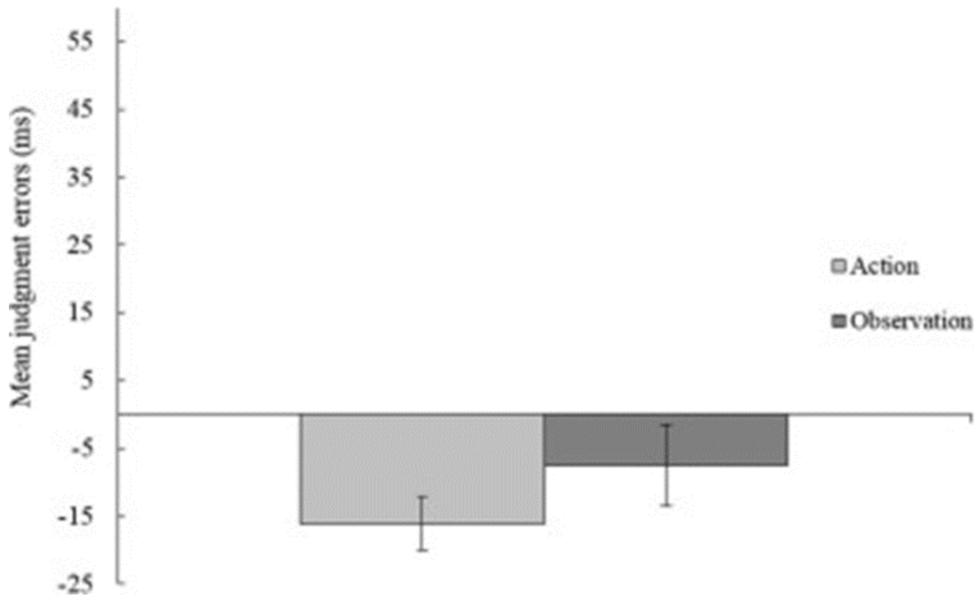

Fig. 3. Mean judgment errors for 'Action' and 'Observation' conditions; bars indicate standard error.

2.9. Results for Cooperation, Competition, and Sequence

A 3 x 2 repeated measures ANOVA on mean judgment errors with *condition* (Cooperation, Competition, Sequence) and *tone* (T1, T2) as within subjects factors revealed a main effect of *tone* ($F_{(1,19)} = 88.796$, $p < .0001$, $\eta^2_p = .824$), indicating an anticipated perception of T1 (self-generated) tone ($M = -7.05$, $SE = 7.65$) as compared to T2 (other-generated) ($M = 50.35$, $SE = 4.40$). Neither the main effect of *condition* ($p = .882$) nor the interaction *tone* by *condition* ($p = .599$) reached significance, suggesting that the relation between the judgments of T1 and T2 did not vary significantly across conditions (see Fig. 4).

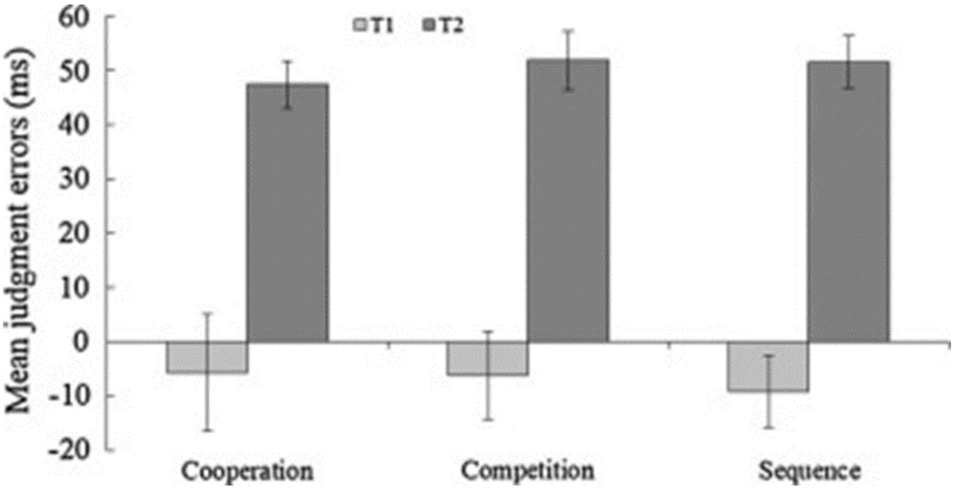

Fig. 4. Mean judgment errors for 'Cooperation', 'Competition', 'Sequence' conditions; bars indicate standard error.

Additional *t*-tests carried out to verify differences between the perception of the self-generated tone in the 'Action' condition and the self-generated tone (T1) in the 'Cooperation', 'Competition', and 'Sequence' conditions revealed no significant differences ($.181 < ps < .274$). In marked contrast, the perception of the other-generated tone (T2) in the 'Cooperation', 'Competition', and 'Sequence' conditions was always delayed in comparison to the 'Observation' condition (Cooperation: $M = 47.48$, $SE = 4.37$, $t_{(19)} = -8.922$, $p < .0001$; Competition: $M = 51.9$, $SE = 5.43$, $t_{(19)} = -8.358$, $p < .0001$; Sequence: $M = 51.67$, $SE = 4.81$; $t_{(19)} = -7.390$, $p < .0001$).

2.10. Discussion of Experiment 1

The results of Experiment 1 clearly showed an *anticipation* temporal judgment bias for self-generated tones. This effect was found in all experimental conditions. In marked contrast, for other-generated tones, we found a *repulsion* temporal judgment bias (delayed perception) in both cooperative and competitive interactions. Furthermore, a similar result was observed for other-generated tones in the 'Sequence' condition, suggesting that regardless of the nature of the cause (human vs. non-human) and the interaction (cooperative vs. competitive), the other-generated tone was perceived as further apart in time than it actually was.

This finding was unexpected, and might be taken to reflect the operation of an inverse binding, whose function is to separate in time, and thus to discriminate, self-generated effects and other-generated effects. This inverse binding mechanism would distinguish the effects of our actions from the effects of others' actions and even from events in the environment, and might thus contribute to safeguard a coherent experience of agency.

According to this hypothesis, the repulsion bias should only be experienced when the second event is preceded by a self-generated event. To test this, in a second, control experiment (Experiment 2), we asked participants to judge the timing of two consecutive other-generated tones.

3. Experiment 2

Apparatus, methods, and procedure were identical to the 'Sequence' condition in Experiment 1, except that participants were exposed to a succession of two tones not contingent on action. If the delayed perception of the other-generated tone observed in Experiment 1 reflects the operation of an inverse binding mechanism, then it should be restricted to situations in which a second tone follows a self-generated tone. We would thus not expect any repulsion effect for a succession of two other-generated tones. On the contrary, if the repulsion reflects a more general mechanism whose function is to separate consecutive events in time, then a similar effect should be expected.

3.1. Participants

Eighteen volunteers (10 females, 8 males; age range = 18–29 years) participated, all had normal or corrected-to-normal vision, were right handed, and were naïve with respect to the purpose of the study.

3.2. Procedure

Participants had to judge the timing of two consecutive tones (T1 and T2) not contingent on action. After each trial started, T1 (a 100 ms tone, 1000 Hz) occurred randomly in the second clock-rotation. This was followed by T2 (a 100 ms tone, 500 Hz) after a fixed interval (629 ms). As in Experiment 1, T1 was always a 1000 Hz tone, while T2 was always a 500 Hz tone. Participants were asked to judge either the timing of T1 or of T2. Instructions of which of the two tones was to be judged appeared every ten trials in counter-balanced order (Fig. 2b).

3.3. Data analysis and results

As in Experiment 1, we calculated a judgment error for each trial by comparing the subjects' judgments on the timing of the occurrence of the tones with the actual position of the hand at the moment of the tones. Again, negative judgment errors indicate anticipated perception; positive judgment errors indicate delayed perception. A few trials (1.8%) were excluded from the analysis because of errors by the subjects or the experimenter. Mean judgment errors were used for statistical analysis. As displayed inFig. 5, participants showed an anticipated perception of both T1 ($M = -27.16$, $SE = 3.85$) and T2 ($M = -19.75$, $SE = 2.72$) ($t_{(17)} = -2.075$, $p = .054$) (Fig. 5).

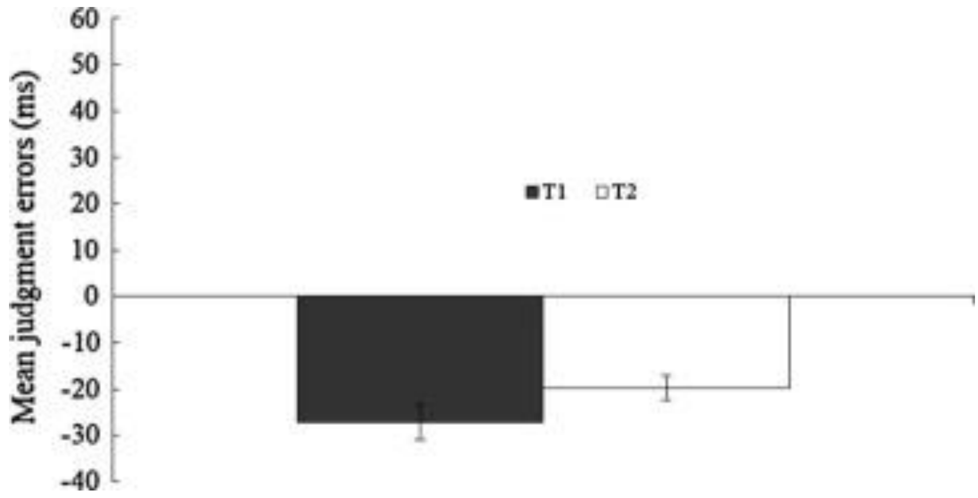

Fig. 5. Mean judgment errors for the timing of T1 and T2; tones in Experiment 2 were not performed by any action. Bars indicate standard error.

4. General discussion

The present study aimed at investigating how action effects are perceived in joint actions sequences. During the sequence of joint actions, participants showed a repulsion temporal judgment bias of the timing of the other-generated event, both for the ‘Cooperation’ and the ‘Competition’ conditions. Even more surprisingly, data showed a similar repulsion effect also for the ‘Sequence’ condition, i.e. when the second event was not produced by a human action (Experiment 1).

Since the belief of causality was preserved, as suggested by the reports in the debriefing session, the absence of difference among experimental conditions cannot be attributed to the use of the same fixed interval between T1 and T2. In line with this, recent evidence suggests indeed that the belief of causality has a primary role not only in respect to the actual cause (Desantis, Roussel, & Waszak, 2011), but also in respect to the actual timing of events (Bechlivanidis and Lagnado, 2016 and Desantis et al., 2016).

Critically, a repulsion effect was not observed when a second event did not follow a self-generated event (Experiment 2). This indicates that the repulsion temporal judgment bias did not arise in response to the mere perception of two sequential events, but rather, to the perception of an event immediately following a self-generated one. Therefore, a plausible explanation is that this repulsion temporal judgment bias contributes to discriminate self-generated events from other events of the environment and to preserve a self-related sense of agency.

Previous literature suggests that temporal judgment biases have a critical role in 'preserving' the sense of agency. Desantis et al. (2011), for example, examined TB for performed and observed actions, manipulating the belief of causality. Participants showed stronger TB when they believed that they had caused the tone in comparison to when they believed that another person had caused the tone. Similarly, Haering and Kiesel (2012) manipulated causal beliefs in a task in which participants had to judge whether or not two events, caused by a key press, appeared simultaneously. When participants believed they had caused the appearance of one of the two events, they perceived this event earlier in time with respect to the other (despite the two events were simultaneous). Our results add to this literature by showing that pre-reflective mechanisms to preserve the sense of agency are necessary also in sequences of events following a self-generated one. Interestingly, the mechanism at play seems to act via a delayed perception of the second event, rather than via a stronger anticipation of the self-generated event.

The idea of an inverse binding, that pushes away other events from the self, is consistent with previous literature. Haggard et al. (2009), for example, found a repulsion effect for events following inhibited actions. Authors argued that the event may seem "particularly unexpected because the action intended to cause it was inhibited, and never actually occurred. The goal event would not be linked to the intention, but "disowned" and kept mentally distinct from it" (p. 107). Similarly, Tsakiris and Haggard (2003) reported a repulsion effect for an event caused by a TMS

induced involuntary movement (Tsakiris & Haggard, 2003). Results showed an anticipation bias (namely TB) for effects produced by voluntary actions, but not for effects produced by TMS induced involuntary actions (for which a repulsion effect occurred). These effects of repulsion may well be interpreted as expressions of a mechanism intended to keep the consequences of voluntary actions separated from other-generated events, via a "disownment" of the latter.

It is worth noticing that the specificity of the abovementioned effect may also explain why, in a similar paradigm, Pfister and colleagues (Pfister, Obhi, Rieger, & Wenke, 2014) did not find a significant TB effect for other-generated actions and the related effects (Experiment 2). While the task of their work was similar to ours, the methodology they used for measuring TB effects was that of the interval estimation between events (e.g., an action and its effects), rather than the temporal perception of the occurring of a single event (i.e., an action or its effect). The investigation of the temporal perception related to the effects of actions allowed us to point the absence of the classic temporal binding estimation in the 'repulsion' of the other-generated effect.

5. Conclusions

In summary, previous research has shown that similar temporal judgment biases emerge in the perception of self-generated and other-generated events (e.g., Wohlschläger et al., 2003). Hence, they appear to act as sort of *agent-serving biases*, binding an effect to the agent who caused it (Frith, 2013), whether self or other. Here we show another facet of temporal judgment biases, which is that of *self-serving biases*: when other-generated events follow a self-generated event, an inverse binding occurs to distinguish the effects of our actions from other events in the environment. We suggest that this mechanism may be critical to preserve our experience of agency against other surrounding events. Further research is needed to clarify the conditions in which this mechanism emerges.

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